Extreme mobility enhancement of two-dimensional electron gases at oxide interfaces via charge transfer induced modulation doping

Chen, Yunzhong; Trier, Felix; Wijnands, T. ; Green, R. J. ; Gauquelin, N. ; Egoavil, R. ; Christensen, Dennis Valbjørn; Koster, G.; Huijben, M. ; Bovet, N.

Total number of authors:
24

Publication date:
2015

Document Version
Peer reviewed version

Extreme mobility enhancement of two-dimensional electron gases at oxide interfaces via charge transfer induced modulation doping

Yunzhong Chen[1], F. Trier[1], T. Wijnands[2], R. J. Green[3], N. Gauquelin[4], R. Egoavil[4], D. V. Christensen[1], G. Koster[2], M. Huijben[2], N. Bovet[5], S. Macke[3], F. He[6], R. Sutarto[6], J. A. Sulpizio[7], M. Honig[7], G. E. D. K. Prawiroatmodjo[8], T. S. Jespersen[8], S. Linderoth[1], S. Ilani[7], J. Verbeeck[4], G. Van Tendeloo[4], G. Rijnders[2], G. A. Sawatzky[3] and N. Pryds[1]

1 Department of Energy Conversion and Storage, Technical University of Denmark, Ris Campus, 4000 Roskilde, Denmark

2 Faculty of Science and Technology and MESA+ Institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands

3 Quantum Matter Institute, Department of Physics and Astronomy, University of British Columbia, Vancouver, British Columbia V6T 1Z1, Canada.

4 EMAT, University of Antwerp, Groenenborgerlaan 171, 2020 Antwerp, Belgium.

5 Nano-Science Center, Department of Chemistry, University of Copenhagen, 2100 Copenhagen, Denmark

6 Canadian Light Source, University of Saskatchewan, Saskatoon, SK S7N2V3, Canada.

7 Department of Condensed Matter Physics, Weizmann Institute of Science, 76100 Rehovot, Israel.

8 Center for Quantum devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark

The discovery of two-dimensional electron gases (2DEGs) at the interface between two insulating complex oxides, such as LaAlO3 (LAO) or gamma-Al2O3 (GAO) epitaxially grown on SrTiO3 (STO) [1,2], provides an opportunity for developing all-oxide electronic devices[3,4]. However, large enhancement of the interfacial electron mobility remains a major and long-standing challenge for fundamental as well as applied research of complex oxides. Here, with in mind the intrinsic electronic structure of the STO 2DEG[5], we inserted a single unit cell insulating layer of polar La1-xSrxMnO3 (x=0, 1/8, and 1/3) at the interface between disordered LaAlO3 and crystalline SrTiO3 created at room temperature. We find that the electron mobility of the interfacial 2DEG is enhanced by more than two orders of magnitude. Our in-situ and resonant x-ray spectroscopic in addition to transmission electron microscopy results indicate that the manganite layer undergoes unambiguous electronic reconstruction and leads to modulation doping of such atomically engineered complex oxide heterointerfaces. Moreover, the manganite spacer suppresses significantly the formation of oxygen vacancies on the STO side by preventing the interfacial redox reaction [6], which underlies the key to achieve the pure electronic reconstruction at the buffered interface. At low temperatures, the modulation-doped 2DEG exhibits clear Shubnikov-de Haas oscillations and the initial manifestation of the quantum Hall effect, demonstrating an unprecedented high-mobility and low electron density oxide 2DEG system. These findings open new avenues for oxide electronics.

[1] Ohtomo, A. Hwang, H. Y. A high-mobility electron gas at the LaAlO3/SrTiO3 heterointerface. Nature 427, 423-426 (2004).
[2] Chen Y. Z. et al. A high-mobility two-dimensional electron gas at the spinel/perovskite interface of -Al2O3/SrTiO3. Nat. Commun. 4,1371 (2013).
[3] Mannhart, J. Schlom, D. G. Oxide interfaces: An opportunity for electronics. Science 327, 1607-1611 (2010).
[4] Miletto Granozio, F., Koster, G. Rijnders, G. Functional oxide interfaces. MRS Bullettin 38, 1017 (2013).
[5] Gabay, M. Triscone, J-M. Oxide heterostructures: Hund rules with a twist. Nature Phys. 9, 610 (2013).
[6] Chen, Y. Z. et al. Metallic and insulating interfaces of amorphous SrTiO3-based oxide heterostructures. Nano. Lett. 11, 3774 (2011).